DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING
DIVISION OF WATER SUPPLY

HYDROGEOLOGIC STUDY REQUIREMENTS FOR THE DELINEATION OF ZONE II AND ZONE III FOR NEW SOURCE APPROVALS

INTRODUCTION

The purpose of this document is to provide more detailed procedures for assisting consultants in the determination of Zone II (recharege areas to public water supplies). The document will also assist DEQE regional personnel in the review of Zone II and Zone III delineation submittals and promote consistency between regions.

This document is not intended to replace the Guidelines for Public Water Systems, 1979 edition or the Supplement to the Guidelines for Public Water Systems, 1984 edition. It is to be viewed as an interpretation and a clarification of the information necessary to determine the Zone II area to a public water supply as required in the 1984 Supplement. The 1984 Supplement contained a number of revisions and additions that substantially change the type and amount of information that must be submitted for new source approvals. Specifically, the 1984 Supplement requires that all new source approval applications delineate Zones II and III. In the Supplement, Zone II is defined as that area of an aquifer which contributes water to a well under the most severe recharge and pumping conditions that can be realistically anticipated. It is bounded by the groundwater divides which result from pumping the well and by the contact of the edge of the aquifer with less permeable materials such as till and bedrock. At some locations, streams and lakes may form recharge boundaries. Zone III is defined as that land area beyond the area of Zone II from which surface water and groundwater drain into Zone II. The surface drainage area as determined by topography is commonly coincident with the groundwater drainage area and will be used to delineate Zone III. In some locations, where surface and groundwater drainage are not coincident, Zone III shall consist of both the surface drainage and the groundwater drainage areas.

The accurate delineation of Zone II and the identification of potential land use conflicts are becoming much more important as development encroaches upon existing and potential areas of water supply. The delineation of Zone II alerts the water purveyor and DEQE of potential water quality and quantity conflicts. As new groundwater sources are developed, land use controls will become increasingly important in providing an effective protection strategy for the water supply. Delineation of the Zone II targets the area where land use controls should be applied. This document will further define the information necessary to calculate the areal extent of Zone II.

It should be noted that this document was developed for wells in unconsolidated formations. However, with some modification it may be applied to wells finished in bedrock.

SUMMARY OF INFORMATION NECESSARY FOR ZONE II DELINEATION

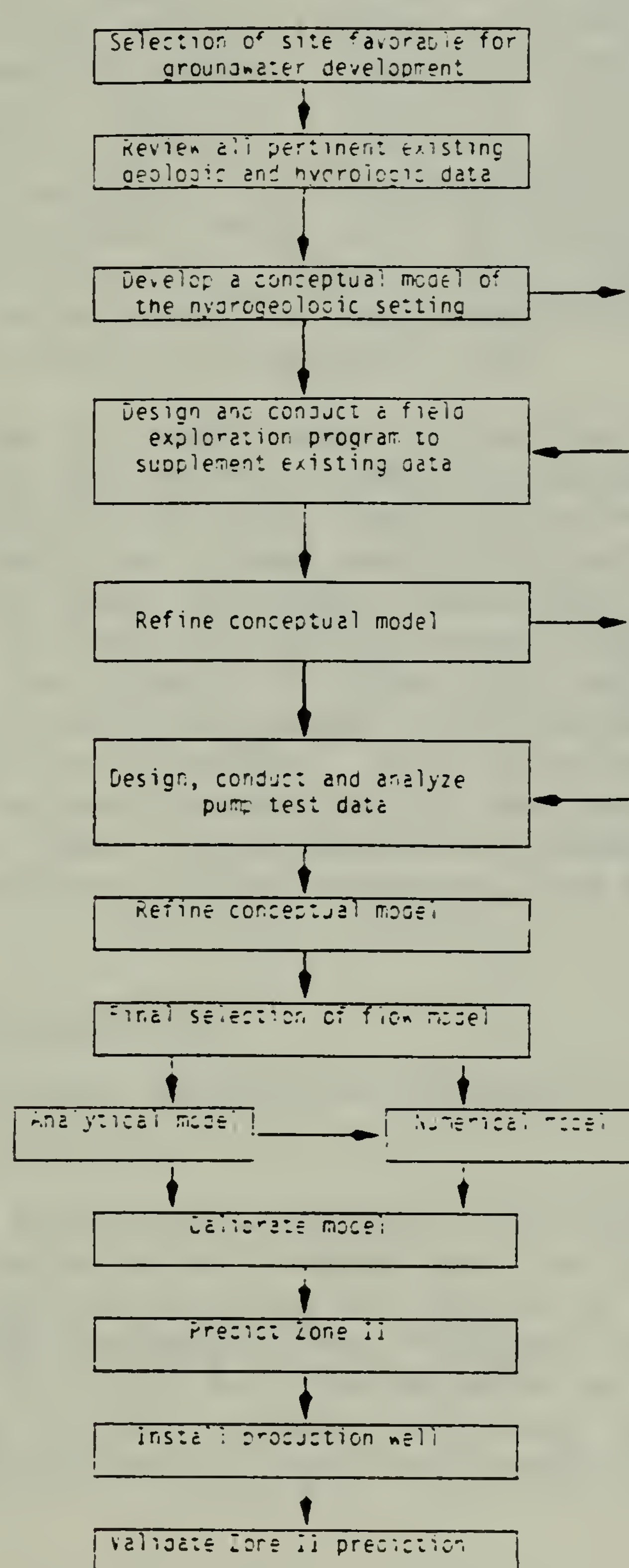
Information needed to determine Zone II includes:

1. A water table contour map representing conditions typical of the pre-developed long-term average water table for an unconfined aquifer and potentiometric surface for a confined aquifer;
2. The hydraulic conductivity, saturated thickness, and storage coefficient of the aquifer;
3. Knowledge of the nature and characteristics of any hydrogeologic boundaries (i.e., no-flow boundaries, fully or partially penetrating streams, and leaky confining layers);
4. The area of contribution to the well for the desired pumping scheme (i.e., safe yield for 180 days).
5. The areal extent of the unconsolidated aquifer upgradient of the proposed well under the proposed safe yield pumping conditions.

(See Page 8 for a more complete description on delineating Zone II)

The following flow chart provides a summary of the steps associated with determining Zone II.

FLOW CHART FOR THE DETERMINATION OF ZONE II



MODELING APPROACHES FOR ZONE II DELINEATION

The conceptual model referred to in the flow chart is an abstract representation of the aquifer system based upon existing data. This conceptual model should be continually refined as more data becomes available in the process of defining Zone II. After the conceptual model is refined based upon newly collected field data, a flow model is selected to simulate the drawdowns necessary to delineate Zone II. Flow models simulate aspects of groundwater flow including flow rate, direction, changes in water levels, and effects of boundary conditions. Both analytical and numerical flow models are available. For the most part, analytical models employ the solution of groundwater flow equations for a simplified aquifer system, such as an areally extensive, isotropic, homogeneous aquifer with constant thickness. Some analytical models are available to solve more complex hydrogeologic situations including boundary conditions. Analytical solutions to groundwater flow equations can be obtained with both hand calculators and computers. They are most useful in analyzing pump test data, evaluating aquifer systems of simple geometry, and designing and verifying numerical models. Numerical models are used to solve large sets of simultaneous equations involving cause and effect relationships in complex aquifer systems. Computer techniques are used to solve the simultaneous equations. Numerical models can be used to deal with problems of greater complexity than would be impractical using analytical models. For example, numerical models allow simulation of variable aquifer thickness, variable aquifer characteristics, complex boundary conditions, and variable recharge and pumping rates.

The type of model used to define Zone II will depend upon the complexity of the aquifer system being evaluated and the amount of data available. Generally, more sophisticated models have greater data requirements. Calibration of both analytical and numerical models with a period for which real cause and effect field data are available is essential. The reliability of the calibration process depends upon the accuracy of the data base, the length of time for which data is available and the complexity of the flow system. Calibration often involves the adjustment of more than one parameter. The limits of adjustments for the parameters and boundaries are dictated by the data base. All types of models require the input of some approximation and assumptions about the aquifer which should be reflected in the interpretation of results for the Zone II delineation.

GROUNDWATER EXPLORATION

The following information relative to the delineation of Zone II and Zone III is necessary:

1. A preliminary estimate of the Zone II and Zone III areas based upon existing information (including information obtained by the exploratory program) should be delineated on the most recent USGS topographic map enlarged to a scale of 1:6000 or smaller. This should be a conservative estimate of these areas which will be further refined following the prolonged pump test and the installation of the final production well.

2. Potential sources of contamination within Zones II and III should be identified on an overlay to the map, as well as the present zoning for these areas.

3. A preliminary discussion of the town's groundwater protection plan for this area should be presented in narrative form.

PUMP TEST

The purpose of conducting the pumping test is to determine the hydraulic characteristics of the aquifer in which the water supply well will be placed: to evaluate the safe well yield; to provide samples for water quality analysis; and to collect the information necessary to delineate the areal extent of Zone II. The pump test should be designed to meet these objectives. A pump test design plan shall be approved by the department prior to conducting the prolonged pump test. Minimum information for the pump test design, performance, and analysis relative to the accurate delineation of Zone II are detailed below:

Pump Test Design:

Pumping Rate - It is important to maintain a constant pumping rate during the 8-inch pump test; therefore, it is recommended that a step drawdown test be conducted prior to the 8-inch pump test to determine the pumping rate in order to determine the optimal pumping rate for the test.

Observation wells - should be placed between the pumping well and any significant hydrogeologic boundaries such as no flow boundaries, constant flux boundaries, constant head boundaries, or leaky layers. Additional wells (multilevel) may also be necessary to measure the effects of partial penetration and vertical leakage. Well placement should allow for the calculation of aquifer transmissivity by distance drawdown as well as time drawdown methods. Quality control measures which ensure that no contamination is introduced into the aquifer should be em-ployed during the drilling and installation of the observation wells.

The response of all wells to changing water levels should be tested by injecting a known volume of water into each well and measuring the subsequent decline of water level. The initial rise of water should be dissipated within a few minutes (to within about 0.01' of the initial rise) if the observation well is to reflect changes of head in the aquifer during the test satisfactorily. Long abandoned wells tend to become clogged, and consequently the response test is one of the most important prepumping examinations to be made if such wells are to be used for observation.

The depth, diameter, and screened interval should be known for each observation well.

The radial distance from the pumping well to each of the observation wells must be determined.

Elevations of all observation wells should be surveyed to a USGS benchmark relative to mean sea level by someone skilled in taking such elevation readings. It is recommended that this be completed prior to the 8-inch pump test; however, if logistics dictate, this may be done during the surveying of the final production well.

An additional observation well should be located outside the area of influence of the well but within the same geologic formation. This well will be used to measure ambient conditions within the aquifer during the pump test.

A plan of the proposed locations and frequency of measurement of all observation wells to be used for drawdown recordings and recovery recordings should be included in the pump test design.

Any observation well that is permanently abandoned subsequent to the completion of the pump test should be filled in such a manner that vertical movement of water within the well bore, including vertical movement of water within the annular space surrounding the well casing, is effectively and permanently prevented, and the water is permanently confined to the specific zone in which it originally occurred.

Induced infiltration - The amount of induced infiltration from a surface water body to the pumping well will directly affect the size and shape of the Zone II area. When recharge from a surface water body to the pumping well is anticipated, the amount of recharge should be estimated during the pump test. Measurements of the physical and chemical properties of the water (pH, specific conductance and temperature) should be taken in the surface water body, the pumping well and appropriate observation wells. When induced infiltration from a surface water body to the well occurs, the water quality of the surface water should be evaluated and consideration given to evaluating the quality of all upstream discharges into the surface water.

Correction for barometric pressure - At all test sites for artesian aquifers, continuous readings of barometric pressure (to a sensitivity of $\pm$ 0.01 inch of mercury) should be made throughout the trend-identification and testing periods. Where appropriate, drawdown data should be adjusted for atmospheric pressure changes occurring during the pump test.

Precipitation - Precipitation which falls during drawdown and recovery should be measured on-site to the nearest one-hundredths of an inch.

Staff gage - When a staff gage is used to measure the elevation of a permanent body of surface water such as a lake or river during the pump test, it should be secured to prevent movement during flood, ice flow, etc.. The effectivesess of using a staff gage to measure flow in a body of water can be increased if the staff gage is encased in a stilling well to minimize disturbance.

Discharge line - The discharge from the pumping test should be located to minimize interference with the physical and chemical hydrogeologic relationships being measured in the pump test. In order to decrease the fluctuations in the pumping rate during early time pumping, it is recommended that the discharge line be filled with water prior to the initiation of the pump test.

Pump Test Performance:

The performance of the pump test will provide the data from which the characteristics of the aquifer can be determined. As such, the importance of maintaining accurate measurements of static water levels, drawdown, pumping rate and time cannot be overemphasized.

The accuracy of drawdown computations relies upon a sound understanding of the static water level in the aquifer. Ideally, water levels in the observations wells should be measured for a period prior to pumping which is equal to the pumping period. At a minimum, ambient conditions should be monitored in target observation wells every other day for a period of five days prior to the pump test.

To provide an accurate determination of aquifer characteristics, drawdown measurements should be carefully observed throughout the pump test. The early time drawdown measurements, which reflect the discharge of water derived from aquifer storage, are the most critical for determining the storage coefficient of the aquifer. Accurate measurement of water level recovery after pumping ceases is also critical in determining aquifer characteristics and should be used to provide a check on aquifer parameters evaluated using drawdown data.

Drawdown - Drawdown in all appropriate wells should be measured with sufficient frequency that each logarithmic cycle in time on the data plots contains at least 10 data points spread throughout the cycle beginning with t= 0.1 minute. In order to accomplish this, continuous electronic recording devices or other mechanical or accoustical method of measurement with the required sensitivity, may be necessary at critical observation wells. Priority should be given to those wells expected to experience significant early time drawdowns.

Recovery readings - Recovery readings should be taken immediately after pump shutdown and with sufficient frequency that each logarithmic cycle in time contains at least 10 data points spread

throughout the cycle beginning with t=0.1 minute, for as many days as the pumping well was pumped, or until change in any 24 hour period is less than 2% of the maximum drawdown in the pumped well, whichever duration is less.

Stabilization - Duration of the Pump Test - The duration of the prolonged pumping test shall be a minimum of five consecutive days with no more than 2.0 hours total per day shutdown permitted (stabilization period excluded) due to equipment malfunctions or maintenance. A pumping well will be considered stabilized if the drawdown reading at the pumping well or observation well has not varied more than 0.5 inches during the final 24 hours.

The duration of the pumping test should be evaluated in relation to the hydrogeologic boundary conditions. The duration shall be lengthened if drawdown in pertinent observation wells has not stabilized or if chemical or physical stability has not been established in wells proximal to surface water boundaries.

Where hydrogeologic conditions and physical withdrawal capacity of the test well dictate, the Department may require further assessment of hydrogeologic boundary conditions and the refinement of Zone II based upon a pump test of the final production well.

Pump Test Analysis:

Pump Test Water Quality Testing and Sampling Requirements - This should be consistent with the Guidelines for Public Water Systems. In addition, water quality sampling should be conducted immediately downgradient of identified potential contaminant sources. The parameters to be tested for at the 8-inch test well and the observation wells should be linked to the types of contamina-tion suspected at the sources.

Hydraulic Conductivity and Storage Coefficent Calculations - The methods used in calculating hydraulic conductivity and storage coefficient from the pump test data must account for conditions found at the test site such as confined conditions, leaky confined conditions, unconfined conditions, and effects of partial penetration. Where appropriate, several methods should be used and compared.

Boundary Conditions - The effects of boundary conditions including a discussion and estimation of induced infiltration, till flux, barrier boundaries and leakage should be presented.

ZONE II CALCULATIONS

A discussion of the proposed methodology for defining Zone II, including how the information from the pump test will be utilized and what other data sources will be used, should be discussed in a report submitted

to DEQE. This discussion should include a presentation of the type of analytical and/or numerical model to be used in defining the area of contribution; reasons for the selection of the model to be used; and plans for calibration and verification of the model.

Minimum information necessary for defining Zone II is as follows:

1. Water table countour map representing conditions typical of the pre-developed long-term average water table for an unconfined aquifer and potentiometric surface for a confined aquifer. An approximation of the slope of the prepumped water table or potentiometric surface should be determined in the vicinity of the anticipated Zone II. This requires that the elevations of the observation wells (or their locations if they have been pulled) be surveyed to a USGS benchmark relative to mean sea level. These readings should then be corrected to represent average conditions.

2. Hydraulic conductivity, saturated thickness, and storage coefficient of the aquifer as calculated from the pump test.

3. Knowledge of the nature and characteristics of any hydrogeologic boundaries.

4. The area of contribution to the well (that is, the cone of depression developed after pumping at safe yield for 180 days without recharge subtracted from the prepumped water table configuration).

5. The appropriate analytical or numerical model should be used to define the area of contribution to the well for the desired pumped scheme (180 days with no recharge).

6. This area should then be extended to the areal extent of the unconsolidated aquifer upgradient of the proposed well under the proposed safe yield pumping conditions.

The key to the determination of Zone II is the prediction of aquifer response to the stresses of a pumping well(s). This is achieved through the direct observation of aquifer response to short-term pumping stress. The measured response to the imposed short-term pumping stress is then used to mathematically simulate the resultant head distribution after long-term pumping is applied (180 days with no recharge from precipitation).

Zone II is determined on a site specific basis by employing the following criteria conditions:

1) Determine the cone of depression that is developed after pumping the well(s) of concern at safe yield [maximum regulated capacity for 180 days with no recharge (locus of 0.1 feet of drawdown)]

2) Superimpose the drawdowns determined in 1) on to the average, steady state aquifer head distribution.

3) Extend the resultant groundwater divide (capture envelope) up-gradient to the intersection of prevalent hydrogeologic boundaries.

4) The land surface projection of 3) is the Zone II area.

The application of these criteria lead to a zone that is usually a sub-set of the aquifer system. This zone provides recharge directly to a well or group of interferring wells. Accordingly, the Zone II area is the most sensitive area of an aquifer from a groundwater supply (well) protection point of view.

SUBMISSION OF THE ZONE II AND ZONE III DELINEATIONS

The following minimum information relative to defining Zone II and Zone III should be included in a hydrogeologic report of the prolonged pumping test which is submitted to the Department's Regional Office.

1. A minimum of two geologic cross sections, one in the direction of groundwater flow and the other perpendicular to it.

2. A discussion of the geologic conditions affecting the site, including boundaries.

3. A contour map of the pre-pumped elevation of the water table with the location and elevations of all observation wells used in the analysis noted.

4. The evaluation of data gathered during the prolonged pumping test.

5. Records of pumping rate and weather conditions.

6. The drawdown readings and recovery readings for all utilized observation wells should be tabulated.

7. Where appropriate, graphs showing drawdown versus time, drawdown versus distance, and recovery versus time. The data shall be plotted on semilogarithmic and log log graph paper.

8. All calculations used to estimate aquifer characteristics.

9. A discussion and comparison of aquifer characteristics obtained from the two or more methods used.

10. A discussion of the methodology used to define Zone II including calibration and verification of the model.

12. An overlay to the above map with existing land uses and zoning for Zones II and III.

13. A detailed discussion of the town's groundwater protection plan for the Zone II and Zone III areas.

APPROVAL CONDITIONS

As related to the hydrogeologic evaluation and Zone II delineation, conditions may be placed on the development of the site for a permanent water supply source. These conditions may include:

1. Target observation wells be left in place for continued monitoring of water levels at a specified frequency.

2. The Zone II delineation be further refined after the installation of the production well. It is advisable upon installation of the final production well that water levels be measured weekly at selected observation wells for the first six months of operation. Once this data has been collected, the consultant should make a determination as to whether to recalibrate the model and recompute the Zone II area. This will require an additional submittal to the Department of the final Zone II.

3. Specific requirements for monitoring activities within the Zone II area that have the potential to threaten the quality or quantity of water in the supply well. Such requirements may include the installation of monitoring wells, the enactment of specific land use controls or any other measures deemed necessary by DEQE to protect the water supply well.

APPROVED ~~BY:~~ Patricia L Deese

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